cules. It may, however, be explained as due to the increasing deposition of carbon with decrease in hydrogen concentration and the preferential occurrence of the reaction between hydrogen and the deposited carbon rather than that between ethane and hydrogen. As we have already observed, our experimental data abundantly confirm this preferential reaction and thus account for the abnormal effect of hydrogen concentration. One alternative possibility is that activation involving the C–C bond requires at least two adjacent elementary spaces of catalyst and that this condition at high hydrogen coverage of the surface might be inversely proportional to a higher power of the hydrogen concentration. Further studies in the general field of hydrocarbon–hydrogen reactions are planned to test these points of view.

Summary

1. The exchange reaction between ethane and deuterium on a nickel catalyst takes place in a lower temperature range, 100–130°, than that required for the interaction to yield methane, 160–300°.

2. The formation of methane by this reaction has been studied kinetically. The surface reaction is inhibited by hydrogen.

3. At low hydrogen concentrations side reactions occur representable by the equations $2C_2H_6 = C + 3CH_4$ and $C + 2H_2 = CH_4$ and these may become the predominant reactions.

4. The activation energy of the reaction on nickel between ethane and hydrogen to form methane is ~43 kcal. The reaction with deuterium is somewhat slower with an activation energy ~0.5 kcal. higher.

5. An interpretation of these data in terms of a dissociative activated adsorption of ethane is given, leading to the conclusion that the activation energy of dissociative adsorption at the C–H bond is greater than that of the C–H bond.

6. A method of preparation of ethane-d_6 has been described.

PRINCETON, N. J. RECEIVED JULY 3, 1936

[CONTRIBUTION NO. 142 FROM THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, RESEARCH LABORATORY OF ORGANIC CHEMISTRY]

Studies in the Urea Series. XIII.[1] Alkyl-nitroureas and Alkyl-nitrobiurets

BY TENNEY L. DAVIS AND NICHOLAS D. CONSTAN

Experiments reported in the tenth paper of this series led to the conclusion that "only those alkylguanidines which contain an unsubstituted amino group form nitro-compounds by direct nitration, the nitro group entering the non-alkylated amino group." A similar generalization is evidently not valid for the alkylureas, for Degner and von Pechmann[2] have reported that N-nitro-N-methylurea is produced by the nitration of methylurea with ethyl nitrate and concentrated sulfuric acid. Thiele and Lachmann[3] on the other hand reported somewhat earlier that ethylurea yields N-nitro-N′-ethylurea by a similar procedure. We have wished to verify this difference between methyl- and ethylurea and to determine in general the behavior of the alkylureas on nitration—and have carried the study farther to the nitration of two ω-substituted biurets and to the preparation from one of the resulting nitro compounds of certain ω,ω,ω′-trisubstituted biurets.

The nitrate of methylurea on treatment with concd. sulfuric acid yields N-nitro-N-methylurea in which the nitro and methyl groups are both attached to the same nitrogen atom, as is demonstrated by the fact that it yields methylnitramine and urea when treated with ammonia. The nitrates of ethyl-, *n*-propyl- and *n*-butylurea on treatment with concd. sulfuric acid yield alkylnitroureas in which the nitro group and the alkyl group are attached to different nitrogen atoms. Unlike methylurea they behave in the same manner as the corresponding alkylguanidines. The structure of the N-nitro-N′-alkylureas is demonstrated by the facts that with ammonia water they yield the alkylureas and with aniline the N-phenyl-N′-alkylureas. As would be expected they dearrange somewhat less readily than nitro-

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[1] Earlier papers of this series: I, Davis and Underwood, THIS JOURNAL, **44**, 2595 (1922); II, VI, VII, VIII, Davis and Blanchard, *ibid.*, **45**, 1816 (1923); **51**, 1790, 1801, 1806 (1929); III, Davis, *Proc. Nat. Acad. Sci.*, **11**, 68 (1925); IV, Davis and Abrams, *Proc. Am. Acad. Arts, Sci.*, **61**, 437 (1926); V, Davis and Luce, THIS JOURNAL, **49**, 2303 (1927); IX, X, Davis and Elderfield, *ibid.*, **54**, 1499 (1932); **55**, 731 (1933); XI, Davis and Farnum, *ibid.*, **56**, 883 (1934); XII, Davis and Ebersole, *ibid.*, **36**, 885 (1934).

(2) Degner and von Pechmann, *Ber.*, **30**, 652 (1897).

(3) Thiele and Lachmann, *Ann.*, **288**, 285 (1895).

urea itself. With cupric salts and pyridine they form colored complex compounds which are soluble in chloroform and may be extracted from aqueous solution by means of that solvent.

The nitrates of N,N-dimethyl-, N,N-diethyl- and N,N-di-*n*-butylurea on treatment with concd. sulfuric acid yield the corresponding dialkylnitramines. No nitrourea derivatives could be found. In one experiment in which N,N-diethylurea nitrate was treated with acetic anhydride, diethylnitramine was produced and a portion of the diethylurea was recovered. The N,N-dialkylureas differ then in their behavior on nitration from N,N-dimethylguanidine, which yields N,N-dimethyl-N′-nitroguanidine.

N,N′-dimethyl- and N,N′-diethylurea could not be nitrated.

ω-Methyl- and ω,ω-dimethylbiuret on nitration with mixed acid yield, respectively, ω-methyl-ω′-nitrobiuret and ω,ω-dimethyl-ω′-nitrobiuret, in which the nitro group has entered the otherwise unsubstituted amino group at the remote end of the molecule. The position of the nitro group is proved by the fact that the nitro compounds react with ammonia to reproduce the original un-nitrated alkylbiurets. A consideration of the facts already known about the urea dearrangement[4] leads to the conclusions (1) that ω-methyl-ω-nitrobiuret would dearrange to form methylnitramine and dicyanic acid and with ammonia water would yield unsubstituted biuret, (2) that ω-methyl-α-nitrobiuret would dearrange to form nitroamide, cyanic acid and methyl isocyanate, and with ammonia water would yield urea and methylurea and (3) that ω-methyl-ω′-nitrobiuret would dearrange to form nitroamide and methyldicyanic acid, and with ammonia water would yield ω-methylbiuret.

$$CH_3NHCONHCONHNO_2 \longrightarrow NH_2NO_2 + CH_3NHCONCO$$

$$CH_3NHCONCO + NH_3 \longrightarrow CH_3NHCONHCONH_2$$

ω,ω-Dimethyl-ω′-nitrobiuret similarly would yield dimethyl-dicyanic acid by dearrangement, and ω,ω-dimethylbiuret by reaction with ammonia. The probable presence of dimethyl-dicyanic acid is further confirmed by the reaction of ω,ω-dimethyl-ω′-nitrobiuret with primary amines.

$$(CH_3)_2NCONCO + RNH_2 \longrightarrow (CH_3)_2NCONHCONHR$$

In this way we have prepared ω,ω,ω′-trimethylbiuret, ω,ω-dimethyl-ω′-*n*-amylbiuret, and ω,ω-dimethyl-ω′-phenylbiuret. None of these tri-substituted biurets gave the biuret test with cupric salts and sodium hydroxide.

Experiments

N-Nitro-N-methylurea.—Twenty-two grams of dry methylurea nitrate, m. p. 125–126°, was added gradually and with stirring to 35 cc. of concd. C. P. sulfuric acid (sp. gr. 1.84) while the temperature was maintained below −15°. The homogeneous mixture was drowned in 120 cc. of ice-water, and the precipitate, washed, dried in a desiccator, and recrystallized from petroleum ether, yielded 8 g. (41.7%) of N-nitro-N-methylurea, m. p. 156–158° with decomposition. The material yielded methylnitramine and urea by interaction with warm ammonia water. Its properties were the same as those reported by Degner and von Pechmann[2] for the N-nitro-N-methylurea prepared by the nitration of methylurea with ethyl nitrate in concd. sulfuric acid solution, and were different from those of the N-nitro-N′-methylurea, m. p. 105–106°, which the same workers prepared by the action of diazomethane on nitrourea.

N-Nitro-N′-ethylurea.—Forty grams of ethylurea nitrate, treated in a similar manner with 60 cc. of concd. sulfuric acid and drowned in 200 cc. of ice-water, yielded 17 g. (49.3%) of N-nitro-N′-ethylurea, pearl-white flakes from petroleum ether, not hygroscopic, m. p. 133–134°. Thiele and Lachmann[3] reported m. p. about 130–131°. The material yielded ethylurea by interaction with warm ammonia water.

N-Nitro-N′-*n*-propylurea.—Fifteen grams of *n*-propylurea nitrate, treated in a similar manner with 23 cc. of concd. sulfuric acid and drowned in 100 cc. of ice-water, yielded 8 g. (60%) of N-nitro-N′-*n*-propylurea, crystals from petroleum ether, m. p. 96°.

Anal. Calcd. for $C_4H_9O_3N_3$: N, 28.5. Found: N, 28.7, 28.6.

The structure of the N-nitro-N′-*n*-propylurea was proved by the fact that it reacted with aniline in warm water to yield N-phenyl-N′-*n*-propylurea, m. p. 116–117°, identified by mixed melting point with a sample prepared by the combination of phenyl isocyanate with *n*-propylamine in benzene solution. Oliveri-Mandalà and Noto[5] reported the melting point of N-phenyl-N′-*n*-propylurea as 114–116°.

***n*-Butylurea Nitrate.**—Twenty-five grams of *n*-butylurea was made into a paste with 25 cc. of water, 20 cc. of nitric acid (sp. gr. 1.42) was added, and the solution was cooled in a freezing mixture of ice and salt. The crystals which separated, after drying in a vacuum desiccator, melted at 62–65°. They were found to be appreciably soluble in benzene; recrystallized from that solvent they yielded the pure substance, m. p. 70–71°, 33 g. (85.5%).

Anal. Calcd. for $C_5H_{13}O_4N_3$: N, 23.5. Found: N, 23.2, 23.3.

N-Nitro-N′-*n*-butylurea.—Thirty grams of *n*-butylurea nitrate, treated with 45 cc. of concd. sulfuric acid and drowned in 150 cc. of ice-water, yielded 18 g. (66.5%) of N-nitro-N′-*n*-butylurea, m. p. 80–81°, pearl-white fluffy leaflets from petroleum ether.

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(4) Especially the seventh and eighth papers of this series.

(5) Oliveri-Mandalà and Noto, *Gazz. chim. ital.*, **43**, I, 517 (1913).

Anal. Calcd. for $C_5H_{11}O_3N_3$: N, 26.1. Found: N, 26.0, 25.9.

The behavior of N-nitro-N′-*n*-butylurea with ammonia and with aniline is typical of the behavior of the N-nitro-N′-alkylureas in general. It reacts less vigorously with these reagents than does nitrourea. The effect of the alkyl group is to reduce the ease of the dearrangement.

Two grams of N-nitro-N′-*n*-butylurea treated with 60 cc. of strong ammonia water gave no evidence of any reaction, and the viscous liquid which remained after spontaneous evaporation was strongly acid to litmus and gave a blue color with a solution of diphenylamine in concd. sulfuric acid. In another experiment, the materials were warmed; a vigorous evolution of nitrous oxide took place, and the evaporation of the liquid on the water-bath gave a residue of *n*-butylurea which, even without purification, failed to give a test for the nitro group with the diphenylamine reagent.

Three grams of N-nitro-N′-*n*-butylurea was treated with a slight excess of aniline dissolved in water. There was no evidence of reaction at room temperature. On spontaneous evaporation of the liquid, aniline separated first and afterward unchanged N-nitro-N′-*n*-butylurea. When a similar mixture was warmed gently it became milky from innumerable small bubbles of nitrous oxide. On continued boiling of the mixture, gassing ceased, and acicular crystals began to separate from the boiling liquid. These on recrystallization from benzene yielded pure N-phenyl-N′-*n*-butylurea, m. p. 129–130°, identified by analysis and by mixed melting point with a sample prepared by the combination of phenyl isocyanate with *n*-butylamine in benzene solution.

Anal. Calcd. for $C_{11}H_{16}ON_2$: N, 14.6. Found: N, 14.8, 14.3.

***n*-Amylurea nitrate,** m. p. 75°, was prepared in the same way as the nitrate of *n*-butylurea.

Anal. Calcd. for $C_6H_{15}O_4N_3$: N, 21.8. Found: N, 21.9, 22.0.

N-Nitro-N′-*n*-amylurea.—Twelve grams of *n*-amylurea nitrate, treated with 16 cc. of concd. sulfuric acid and drowned in 80 cc. of ice-water, yielded an oil which on chilling solidified to crystals. These, dried and recrystallized from ether, gave 6 g. (67%) of N-nitro-N′-*n*-amylurea, m. p. 62°.

Anal. Calcd. for $C_6H_{13}O_3N_3$: N, 24.6. Found: N, 24.6, 24.7.

By reaction with aniline in warm water N-nitro-N′-*n*-amylurea yielded N-phenyl-N′-*n*-amylurea, m. p. 92°, identified by analysis and by mixed melting point with a sample prepared by the combination of phenyl isocyanate with *n*-amylamine in benzene solution.

Anal. Calcd. for $C_{12}H_{18}ON_2$: N, 13.6. Found: N, 13.5.

N,N-Dimethylurea nitrate was prepared by the same method as the nitrate of butylurea, 86.8% yield, crystals from benzene, m. p. 103–104°.

Anal. Calcd. for $C_3H_9O_4N_3$: N, 27.8. Found: N, 28.0, 28.2.

Ten grams of N,N-dimethylurea nitrate was treated with 15 cc. of concd. sulfuric acid and drowned in 75 cc. of of ice-water, as described, but no precipitate appeared. The liquid was extracted repeatedly with small portions of ether, and the ether extract, evaporated and cooled to a low temperature, gave stout needle crystals of dimethylnitramine, m. p. 79°. Franchimont[6] obtained the same material by the action of strong nitric acid on the nitrate of N,N-dimethylurea.

N,N-Diethylurea nitrate was prepared by the same method as the other nitrates, 77% yield, crystals from benzene, m. p. 118°.

Anal. Calcd. for $C_5H_{13}O_4N_3$: N, 23.5. Found: N, 23.7, 23.5.

Twelve grams of N,N-diethylurea nitrate was treated with 16 cc. of concd. sulfuric acid and drowned in 80 cc. of ice-water, the liquid was extracted with ether, and the ethereal extract on distillation in vacuum yielded a small amount of diethylnitramine boiling as reported at 93° at 16 mm. pressure.[7] In another experiment the sulfuric acid solution of N,N-diethylurea nitrate was diluted with ether before it was poured into water, but no nitrodiethylurea was obtained. In another, acetic anhydride was used instead of sulfuric acid; some diethylnitramine was produced and a portion of the N,N-diethylurea nitrate was recovered unchanged.

N,N-Di-*n*-propylurea nitrate was procured in excellent yield by the same method as the other nitrates, m. p. 165°.

Anal. Calcd. for $C_7H_{17}O_4N_3$: N, 20.3. Found: N, 20.5, 20.4.

On treatment with sulfuric acid, water and ether in the same manner as the other nitrates, it yielded a small quantity of di-*n*-propylnitramine boiling as reported at 76–79° at 10 mm. pressure.[8]

Action of Sulfuric Acid on the Nitrates of N,N′-Dialkylureas.—Ten grams of finely powdered dry N,N′-dimethylurea nitrate was added gradually to 15 cc. of concd. sulfuric acid while the mixture was kept at a temperature below −15°. When the liquid was poured into 75 cc. of ice-water, no precipitate appeared. Ether and benzene extracts of the acid solution gave no residues when they were evaporated. The solution was treated with barium carbonate in excess, filtered, and evaporated to dryness at a temperature below 55°. Ether, petroleum ether, and benzene extracts of the residue gave no products which showed a positive test with the diphenylamine reagent.

An experiment with the nitrate of N,N′-diethylurea gave a similar result.

In another experiment with N,N′-dimethylurea nitrate, the sulfuric acid solution was diluted with ether instead of with water. The ether removed most of the sulfuric acid. In order to determine whether any cyanic acid from the dearrangement of the N,N′-dimethylurea was present, the residue from the ether was treated with benzylamine in the expectation that the cyanic acid, if present, would combine with that material to form benzyl- or dibenzylurea, but only benzylamine sulfate, nitrate and N,N′-dimethylurea were identified in the mixture.

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(6) Franchimont, *Rec. trav. chim.*, **2**, 122 (1883).

(7) Franchimont and Umgrove, *ibid.*, **16**, 396 (1897).

(8) Thomas, *ibid.*, **9**, 79 (1890).

ω-Methyl-ω′-nitrobiuret.—Four grams of finely powdered dry ω-methylbiuret[9] was added gradually and with stirring to a mixture, below −15°, of 12 cc. of concd. sulfuric acid (1.84) and 3 cc. of nitric acid (1.42). On drowning the clear liquid in 25 cc. of ice-water, the ω-methyl-ω′-nitrobiuret precipitated as an almost impalpable powder. Washed with ice-water and dried in vacuum, this yielded without recrystallization 2.9 g. (52%) of product which did not melt but decomposed at 99–100°.

Anal. Calcd. for $C_3H_6O_4N_4$: N, 34.5. Found: N, 34.5, 34.6.

ω-Methyl-ω′-nitrobiuret did not yield a chloroform soluble copper pyridine complex. Warmed with ammonia water, it yielded ω-methylbiuret, identified by mixed melting point with a known sample.

ω,ω-Dimethyl-ω′-nitrobiuret.—Ten grams of ω,ω-dimethylbiuret, nitrated with a mixture of 18.5 cc. of concd. sulfuric acid (1.84) and 4.5 cc. of nitric acid (1.42) and drowned in 100 cc. of ice-water, gave 9.8 g. (73%) of ω,ω-dimethyl-ω′-nitrobiuret, m. p. 114–115°, with decomposition.

Anal. Calcd. for $C_4H_8O_4N_4$: N, 31.8. Found: N, 31.7, 31.4.

ω,ω-Dimethyl-ω′-nitrobiuret, warmed with ammonia water, yielded ω,ω-dimethylbiuret, identified by mixed melting point with a known sample. It did not form a chloroform soluble copper pyridine complex.

ω,ω-Dimethyl-ω′-phenylbiuret.—Two grams of ω,ω-dimethyl-ω′-nitrobiuret was treated with a slight excess of aniline in aqueous solution. Gassing set in at once. The material was warmed until gassing ceased and evaporated to dryness on the water-bath. The product was purified by recrystallization from methyl alcohol and by sublimation in vacuum. At ordinary pressure it sublimed without melting at about 225°.

Anal. Calcd. for $C_{10}H_{13}O_2N_3$: N, 20.3. Found: N, 20.6.

ω,ω,ω′-Trimethylbiuret, prepared in similar manner from ω,ω-dimethyl-ω′-nitrobiuret and methylamine, melted at 154°, small crystals from chloroform.

Anal. Calcd. for $C_5H_{11}O_2N_3$: N, 29.0. Found: N, 29.2, 29.3.

ω,ω-Dimethyl-ω′-*n*-amylbiuret, prepared in similar manner from ω,ω-dimethyl-ω′-nitrobiuret and *n*-amylamine, melted at 149°, small crystals from chloroform.

Anal. Calcd. for $C_9H_{19}O_2N_3$: N, 20.9. Found: N, 21.1.

Very few substituted biurets containing substituents in both the ω- and the ω′-positions are described in the literature. Experimentation along this line is being continued.

Summary

The nitration of alkylureas has been studied by the method of treating the urea nitrates with concentrated sulfuric acid.

Ethyl-, *n*-propyl- and *n*-butylurea, like the corresponding guanidines, nitrate in the non-alkylated amino group.

Methylurea, unlike methylguanidine, nitrates on the nitrogen atom which is attached to the methyl.

Dialkylureas in which the two alkyl groups are attached to the same nitrogen atom yield dialkylnitramines.

Dialkylureas in which the two alkyl groups are attached to different nitrogen atoms could not be nitrated.

ω-Methyl- and ω,ω-dimethylbiuret with mixed acid take on a nitro group in the non-alkylated amino group at the remote end of the molecule.

Three ω,ω,ω′-trisubstituted biurets are described.

CAMBRIDGE, MASS. RECEIVED JULY 1, 1936

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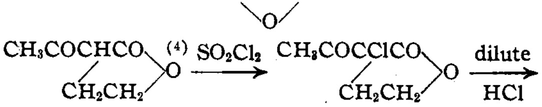
(9) Prepared according to the method of Davis and Blanchard, seventh paper of this series.

[CONTRIBUTION FROM THE CHEMISTRY LABORATORY OF THE JOHNS HOPKINS UNIVERSITY]

Studies of Crystalline Vitamin B₁. XIV. Sulfite Cleavage. IV. The Thiazole Half

BY EDWIN R. BUCHMAN

The vitamin B_1 molecule is split by sulfite[1] yielding 4-methyl 5-(β-hydroxyethyl) thiazole[2] as basic cleavage product. The synthesis of this substance from brominated acetopropyl alcohol and thioformamide was announced[3] over a year ago. Subsequently H. T. Clarke and S. Gurin prepared[2] the compound in connection with their establishment of the presence of the thiazole nucleus in the vitamin. Recently the following improved method has been developed.



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(1) R. R. Williams, R. E. Waterman, J. C. Keresztesy and E. R. Buchman, THIS JOURNAL, **57**, 536 (1935).

(2) H. T. Clarke and S. Gurin, *ibid.*, **57**, 1876 (1935).

(3) E. R. Buchman and R. R. Williams, Paper read before the Organic Division of the American Chemical Society at the New York meeting, April, 1935.

(4) I. L. Knunyantz, G. V. Chelintzev and E. D. Osetrova, *Compt. rend. acad. sci.* (U. R. S. S.), [N. S.], **1**, 312 (1934); *C. A.*, **28**, 4382 (1934).